Note on the Scattering of α-Particles.

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In a previous paper on the scattering of the α-particles by matter the author has described experiments which allowed a direct determination of the most probable angle through which an α-particle is deflected when passing through a thin film of matter.* In these experiments an intense, narrow and parallel pencil of α-particles was allowed to fall on a zinc sulphide screen, and the distribution of the scintillations over that screen was determined when the pencil was intercepted by sheets of metal of various thickness and material. Measurements were also made for α-particles of varying speed. From this distribution the most probable deflection suffered by the α-particle in each particular case was easily deduced. These deductions were based on the assumption that the scattering of the pencil is the result of a multitude of small deflections suffered by the α-particles in their encounters with the atoms of the scattering foil. This type of scattering has recently been termed by Rutherford† "compound scattering" in order to distinguish it from another type, denoted as "single scattering," which concerns the deflections through large angles of an α-particle in a single collision.

The first section of this paper deals with the distribution of the scattered α-particles on the screen; the second discusses the connection between the thickness of foils and the most probable angle of scattering which they produce. It will not be necessary to make any special assumptions as to the laws of action and reaction between the atom and the α-particle; it suffices only to suppose that the deflection in each single collision is small compared with the final deflection after passing through the scattering foil. This paper, therefore, does not deal with the large scattering observed by Geiger and Marsden‡ which has been ascribed by Rutherford to single collisions. Such large deflections are rare, and can be neglected in the consideration of the deflections through small angles.

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* H. Geiger, 'Roy. Soc. Proc.,' 1910, vol. 83, p. 492.

† E. Rutherford, 'Phil. Mag.,' 1911, vol. 21, p. 669.

‡ H. Geiger and E. Marsden, 'Roy. Soc. Proc.,' 1909, vol. 82, p. 495.

(1) *Distribution Curve of the α-Particles.*

A parallel pencil of α-particles of infinitely small cross-section is supposed to pass through a scattering foil and then to fall upon a zinc sulphide screen. Taking rectangular co-ordinates in the plane of the screen with the point of incidence of the unscattered beam as origin of the system, the angle through which an α-particle is turned when passing through the foil may be measured by the co-ordinates of the point of impact of this particle on the screen. This is justifiable, since all scattering takes place at the same distance from the screen, and since we are only dealing with very small angles of the order of a few degrees. By the law of errors we find that the probability of p of an α-particle hitting the element $dx\,dy$ at the point x, y of the screen is given by

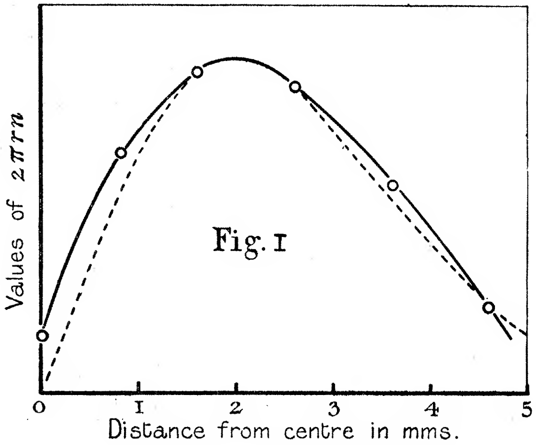
$$p = \frac{1}{2\,l^2\pi}\,e^{-(x^2+y^2)/2\,l^2}dx\,dy. \qquad (1)$$

Introducing polar co-ordinates and integrating with respect to the angle between 0 and $2\,\pi$ we obtain the probability P_r of any deflection r from the centre, namely,

$$P_r = \frac{r}{l^2}e^{-r^2/2\,l^2}dr. \qquad (2)$$

The curve represented by this equation has a maximum for $r = l$, and l is therefore the most probable deflection on the screen, or l/d is the most probable angle of deviation, d being the distance from scattering foil to screen.

The average value of r is found by integrating rP_r from 0 to ∞. The result is $\bar{r} = \frac{1}{2}\,l\sqrt{(2\,\pi)}$ or 1·25 l approximately. The average deflection is therefore 1·25 times greater than the most probable deflection.



The curve represented by the above equation is in good agreement with the experimental curves which were given in figs. 2 and 3 of the paper quoted above. For comparison, the curve of fig. 2 is drawn again in the accompanying diagram (fig. 1 of this paper), the theoretical curve being represented by the dotted line. The most probable deflection l is taken equal to 2. The difference between the two curves near the origin is due to the finite cross-section of the beam used in the experiment.

(2) *Variation of Scattering Angle with Thickness of Foil.*

We must first discuss the composition of successive scattering angles. Let us assume that a scattering foil F placed at a distance d from the screen may scatter the α-particles so that a most probable deflection l_1 is obtained on the screen. The probability p_1 that an α-particle hits an element $dx_1\,dy_1$ at the point x_1, y_1 of the screen is then given by

$$p_1 = \frac{1}{2\pi l_1^2} e^{-(x_1^2+y_1^2)/2\,l_1^2} dx_1\,dy_1. \tag{3}$$

Let us next consider the effect of an additional scattering foil placed directly in front of the first one. Let the second foil *alone* produce a most probable deflection l_2 of an α-particle on the screen. *Combined* with the first foil it will produce an additional deflection of the particle from the point x_1, y_1 to the point x_2, y_2. The probability p_2 of this deflection is

$$p_2 = \frac{1}{2\pi l_2^2} e^{-[(x_2-x_1)^2+(y_2-y_1)^2]/2\,l_2^2} dx_2\,dy_2. \tag{4}$$

The probability that the α-particle, after passing through the two foils, hits the screen at the point x_2, y_2 is given by the integral with respect to x_1, y_1 of the product of the two independent probabilities p_1 and p_2.

This probability is :—

$$\mathrm{P} = \frac{dx_2\,dy_2}{4\pi^2 l_1^2 l_2^2} \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} e^{-[l_2^2(x_2^2+y_2^2)+l_1^2(x_1-x_2)^2+l_1^2(y_1-y_2)^2]/2\,l_1^2 l_2^2} dx_1 dy_1.$$

The exponent may be written in the form

$$-\frac{x_2^2+y_2^2}{2(l_1^2+l_2^2)} - \frac{1}{2l_1^2 l_2^2(l_1^2+l_2^2)}[\{x_1(l_1^2+l_2^2)-x_2 l_1^2\}^2 + \{y_1(l_1^2+l_2^2)-y_2 l_1^2\}^2],$$

and the integration can now be carried out independently for x and y between the limits $-\infty$ and $+\infty$. We obtain

$$\mathrm{P} = \frac{1}{2\pi(l_1^2+l_2^2)} e^{-(x_2^2+y_2^2)/2(l_1^2+l_2^2)} dx_2\,dy_2. \tag{5}$$

Again introducing polar co-ordinates and integrating with respect to the angle, we obtain the probability of a deflection of magnitude r on the screen independent of the direction of this deflection,

$$\mathrm{P} = \frac{r}{l_1^2 + l_2^2} e^{-r^2/2(l_1^2+l_2^2)} dr. \tag{6}$$

This equation is identical with equation (2) except that in this case the constant $l_1^2 + l_2^2$ appears in place of l^2. Consequently, if l_1 and l_2 denote the most probable deflections produced by the foils 1 and 2 independently, then the most probable deflection produced by foils 1 and 2 combined is $\sqrt{(l_1^2 + l_2^2)}$. The above analysis can be extended from two to three foils, and so on. In the case of n foils the most probable deflection is $\sqrt{(l_1^2 + l_2^2 + l_3^2 + \ldots + l_n^2)}$, where $l_1, l_2, \ldots, l_n$, are the most probable angles of deflections produced by each foil separately.

If we consider foils of equal thicknesses and assume that the velocity of the particle does not change in passing through them, we can put $l_1 = l_2 = l_3 = l_n$. Thus it follows that the most probable angle of scattering increases as the square root of the thickness traversed by the particle. This has also been pointed out by Sir J. J. Thomson in a theoretical paper in the 'Proceedings of the Cambridge Philosophical Society,' 1910.

We will now modify the equation obtained above for the variation of the scattering angle with thickness by taking account of the decrease of the velocity of the α-particle when it passes through the foil. On account of the decrease of the velocity the specific scattering coefficient increases, and, as has been shown by experiment with very thin foils, the increase is inversely proportional to the third power of the velocity. In order to deduce the scattering produced by a foil of finite thickness we shall, for convenience, consider that foil as being made up of a number of foils of such thickness that the α-particle in passing through one of them collides with one atom only. If n_0 denotes the range of an α-particle expressed as the number of atoms through which it can penetrate, then its velocity after it has passed through n atoms is given by

$$v^3 = \frac{v_0^3}{n_0}(n_0 - n),$$

and the most probable deflection produced by the nth atom will be

$$l = l_0 \frac{v_0^3}{v^3} = l_0 \frac{n_0}{n_0 - n},$$

where l_0 is the most probable deflection for $v = v_0$, v_0 being the initial velocity of the α-particle.

When the α-particle passes through the first atom, the value of the most probable deflection is $l_1 = l_0 \frac{n_0}{n_0 - 1}$, when it passes through the second the value of l is $l_2 = l_0 \frac{n_0}{n_0-2}$, and so on. The square of the most probable deflection of the particle, after it has passed through n atoms in succession, is given by

$$L^2 = l_1^2+l_2^2+l_3^2+\ldots+l_n^2 = n_0^2 l_0^2 \left[\frac{1}{(n_0-1)^2}+\frac{1}{(n_0-2)^2}+\ldots+\frac{1}{(n_0-n)^2}\right],$$

or, since n is large,

$$L^2 = n_0^2 l_0^2 \int_0^n \frac{1}{(n_0-x)^2}\,dx, \quad \text{leading to} \quad L = l_0\sqrt{\frac{n_0 n}{n_0-n}}.$$

The curve represented by this equation is drawn in fig. 2. According to this relation, the most probable angle of scattering increases for small thicknesses (n small compared with n_0), according to the square root of the thickness. With further increase of thickness, the curve passes through a point of inflection, and is, in fact, nearly a straight line over an appreciable range. For still larger thicknesses, the increase of the most probable angle becomes more and more rapid.

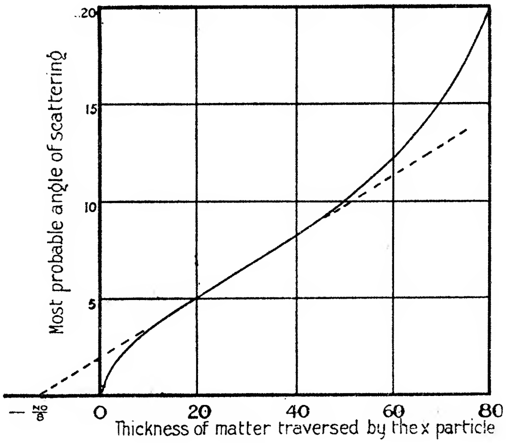


FIG. 2.

The experimental curves, which were given in fig. 5 of the previous paper, are in good agreement with these deductions. Starting from the origin, the experimental curves obtained for different materials show a distinct curvature before they turn into straight lines. The experiments were not carried out with sufficiently large thicknesses to show the final rapid increase of the scattering angle. The range of thickness over which the scattering was investigated corresponds to abscissæ in the above figure smaller than 60. The straight lines obtained in the experiments mentioned above, if produced backwards, all cut the negative X axis at nearly the same distance from the origin. This is also in agreement with the equation, since the tangent at the point of inflection cuts the X axis at the point $-\frac{1}{8}n_0$, a quantity which is independent of the specific properties of the scattering material.

From similar considerations to those given above, it is possible to calculate the scattering of α-particles in gases, and to deduce the scattering coefficients. This question is of interest, since for substances of atomic weight comparable with that of the α-particle, the amount of scattering may not be proportional to the atomic weight, a relation which seems to hold fairly well for the heavier atoms so far examined. A discussion of this will, however, be postponed until the necessary experiments have been carried out.

I take this opportunity of expressing my thanks to Prof. Rutherford for many helpful suggestions.

The Effect of Temperature upon Radioactive Disintegration.

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1. *Introduction.*

Within the last few years the influence of high temperature on the activity of radium emanation, of the active deposit, and of radium C has been examined in detail by several authors. The conclusions arrived at have been conflicting, some workers affirming a positive effect of temperature, others denying it. This lack of agreement is due, however, to a difference in the method of measurement of the active matter under investigation. Those workers who measured the activity by γ-rays are all agreed that temperature has no effect whatever, while those who measured by β-rays found always an effect of some kind, in many cases of considerable magnitude, and often, indeed, of a very surprising nature.

While, however, the fact that there is a β-ray effect is admitted by all, there is still a lack of agreement between the results of the experiments of different workers, and even of different experiments of the same worker, which is hardly to be expected if the effects were due to a definite change in the properties of the disintegrating atoms at high temperatures. In view, therefore, of the uncertainty which has arisen on a point of such